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FORMATION OF SECONDARY DEPRESSIONS IN RELATION TO THE THICKNESS PATTERN

By J. S. SAWYER, M.A.

The thickness chart has recently been brought into increasing use for the purpose of forecasting the development of the synoptic weather situation. Charts of the thickness of the atmospheric layer between pressure levels of 1000 and 500 mb. are used at the Central Forecasting Office, Dunstable, and the properties and significance of such charts have been described by R. C. Sutcliffe[1]*, who has also shown[2] that a theoretical relationship can be established between the curvature and shear of the " thermal-wind"† field and the cyclonic or anticyclonic development which must accompany it. The present note outlines the results of investigations which have recently been conducted in the Forecasting Research Division to determine the characteristic features of the thickness chart which accompany the formation of secondary depressions. So far the study has been confined to secondaries which form either at the point of occlusion of the primary depression or as waves on the warm front; it is hoped to publish a more complete account of the work when it has been extended to other synoptic developments.

Characteristic thickness pattern associated with secondaries at the point of occlusion.—It has been found that secondaries forming at the point of occlusion can be divided conveniently into two types according as the occlusion on which they form is of the cold or warm type. Characteristic patterns associated with secondaries on warm and cold occlusions are illustrated in Figs. 1 and 2.

The features of the isobaric and thickness pattern which are found to provide significant criteria for such development are as follows. For secondary formation at the point of occlusion of a warm occlusion there must be:—

(*a*) a slow-moving primary depression;

(*b*) a notably strong thermal gradient of warm-front type ahead of the primary (somewhere to the east) with the maximum gradient displaced some distance from the centre of the primary. The thermal wind (1000–500 mb.) is usually 40–80 kt.

*The index numbers refer to the list of references on p. 5.

†The thermal wind is obtained by application of the geostrophic wind relation to the thickness chart.

For secondary formation at the point of occlusion of a cold occlusion there must be:—

(*a*) a strong thermal gradient displaced several hundred miles from the centre of the primary—the thermal gradient over the centre of the primary is relatively weak and the primary is usually slow moving.

(*b*) a marked fanning out of the thickness lines ahead of the point of occlusion from the region of strong thermal gradient behind it (*i.e.* usually to the west).

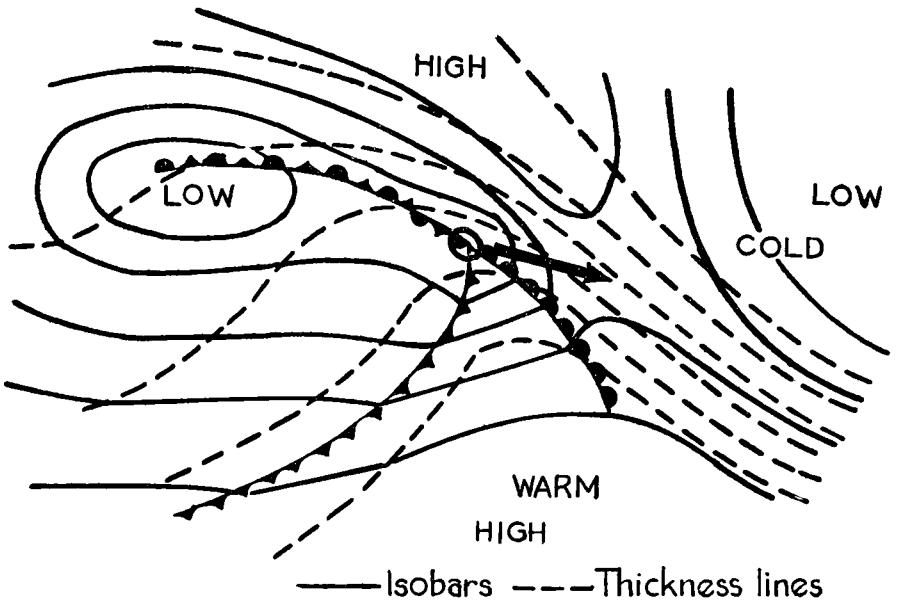

FIG. I—CHARACTERISTIC ISOBARIC AND THICKNESS PATTERN LEADING TO THE FORMATION OF A WARM-OCCLUSION SECONDARY

The fanning out of the thickness lines is conveniently described as " difluence " of the thermal winds, and the converse running together of the thickness lines as " confluence ". In conformity with the rules above, secondaries on warm occlusions form just to the right of a " confluence " in the thermal pattern, and secondaries on cold occlusions form to the left of a " difluence ". These are both areas which R. C. Sutcliffe has shown theoretically to be associated with cyclonic development.

TABLE I—SUMMARY OF RESULTS OF TEST OF CRITERIA FOR THE FORMATION OF SECONDARY DEPRESSIONS AT THE POINT OF OCCLUSION

Period October 1947 – September 1948
Each occlusion is counted once only in the table

	No secondary expected	Cold occlusion secondary expected	Warm occlusion secondary expected
No secondary formed	137	14	9
Secondary formed	14	40	23

Total successes = 200 Total failures = 37

A test of the above criteria has been made on the basis of a series of a year's charts which carried the surface isobars and thickness pattern. In order to

simulate forecasting practice an assessment was made on each chart in respect of each occlusion present as to whether a secondary should, or should not, subsequently form. The results, which are given in Table I, suggest that the rules should provide a useful forecasting tool. The criteria can be regarded as both necessary and sufficient for secondary formation.

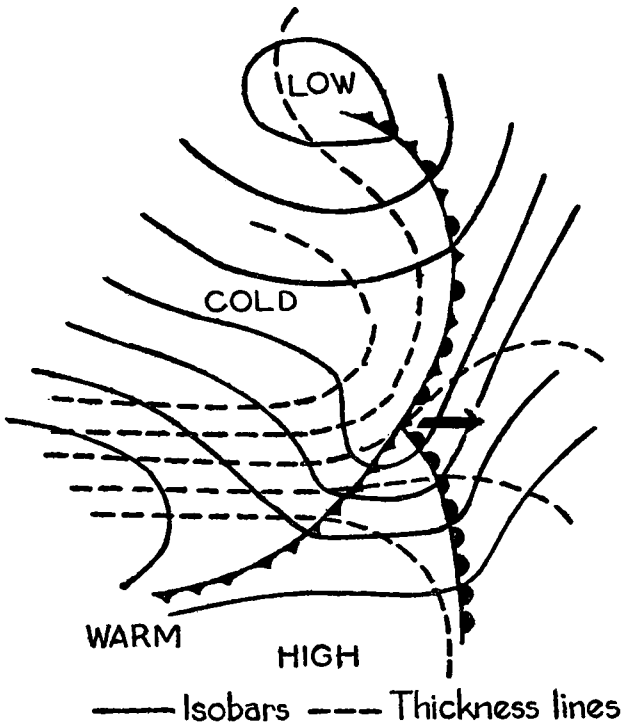

FIG. 2—CHARACTERISTIC ISOBARIC AND THICKNESS PATTERN ACCOMPANYING THE FORMATION OF A SECONDARY ON A COLD OCCLUSION

Characteristic thickness pattern associated with warm-front waves.—The thickness pattern associated with the rather unusual formation of a wave on the warm front of a primary depression has also been investigated. It has been found that the thickness pattern is the same as that associated with warm-occlusion secondaries, and Fig. 3 shows the relation of the fronts to the thickness pattern. Out of 19 warm-front waves noted during the period September 1946–September 1948 only one failed to show these characteristic features. Certain slow-moving secondaries which form on cold fronts have a similar thermal structure to that of the cold-occlusion secondaries, but the usual fast-moving cold-front wave has not yet been studied.

Other characteristics of warm-occlusion secondaries and warm-front waves.—Once formed the behaviour of warm-occlusion secondaries and warm-front waves is very similar. They move quickly away from the primary at a speed usually between 30 and 50 kt. For this reason both types are sometimes referred to as " break-away " depressions. The direction of motion closely follows the thickness line over the centre; but, because of the distortion caused by the secondary itself, it tends to be inclined slightly towards the cold side of the strong thermal belt which existed before the secondary appeared; the average inclination is about 10 degrees for warm-front waves and 30 degrees for warm-occlusion secondaries.

The central pressure of both types of secondary tends to rise, although they may deepen later after they have crossed the ridge ahead of them. However, these secondaries are often responsible for a noteworthy penetration of rain into the high-pressure area.

Characteristics of secondaries on cold occlusions.—The behaviour of secondaries on cold occlusions is less regular than that of those on warm occlusions, and it seems to be more dependent on the details of the thickness pattern around them. If the difluence of the thickness lines is broadly symmetrical, as indicated in Fig. 2, a rather slow motion is usual in the general direction of the strong thermal winds. A speed of 10–20 kt. can be expected. However, if the thermal gradient is stronger in the left-hand or right-hand branch of the difluence, corresponding motion towards the left or right is probable, and the speed is somewhat greater than in the symmetrical case. Although these secondaries often go through a short-lived phase of rapid deepening very few become major features of the synoptic chart.

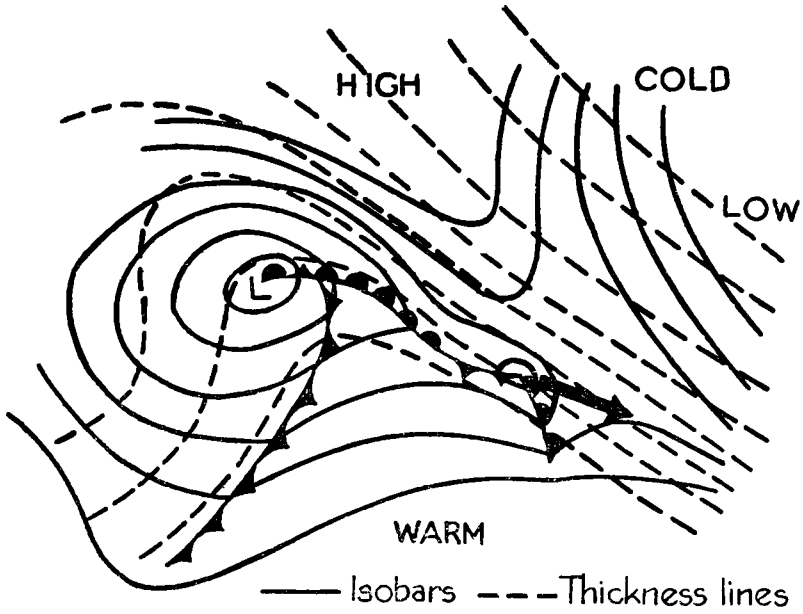

FIG. 3—CHARACTERISTIC ISOBARIC AND THICKNESS PATTERN ACCOMPANYING THE FORMATION OF A WARM-FRONT WAVE

There is an important association between secondaries on cold occlusions and the "jet stream", the narrow belt of exceptionally strong wind in the upper troposphere which has been studied by E. Palmén[3] (see also Meteorological Office Discussion[4] on October 25, 1948). A jet stream will usually be found above the strong thermal belt behind the point of occlusion at which a secondary forms. The secondary forms beneath the left exit from the jet, and the changes in the flow which accompany the development of the secondary result in the extension of the jet in the direction of the stream.

Application to forecasting practice.—The application of the above facts to forecasting practice depends on the forecaster's ability to decide in advance that the characteristic pattern will occur. This is usually possible. Moreover, there is usually a lag of up to 24 hours between the first appearance of the characteristic pattern and the formation of a secondary; the lag is greater for warm-type secondaries.

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ARTIFICIAL NUCLEATION OF CLOUDS

By RONALD FRITH, Ph.D.

Since the reports of the artificial production of precipitation by Langmuir in America[1]* and Kraus and Squires in Australia[2] further experiments on similar lines have been made in those and several other countries. Moreover, the physics of the problem has been extensively discussed by Bergeron[3] and others. The purpose of the present note is to recapitulate some of the main issues which have emerged and to report briefly on a few experiments carried out by the Meteorological Research Flight in the United Kingdom during the past two years.

It is generally accepted that if a cooling agent, for example solid carbon dioxide (dry ice), be scattered into a cloud of supercooled water drops, ice crystals will be formed. Owing to the difference of vapour pressure between ice and supercooled water at the same temperature these ice crystals will grow—and they will grow the more rapidly the greater this difference of vapour pressure and the greater the water content of the cloud. Thus, whenever there are ice crystals present, the amount of supercooled water will decrease steadily and the ice crystals will grow. Eventually the cloud may consist entirely of ice crystals; or it may revert to the supercooled-water state; or it may clear completely—depending on the number of ice crystals present:—

(*a*) With very large numbers of crystals, even when all the water has been sublimated on to the crystals, they are still small and an ice-crystal cloud is left.

(*b*) With very few crystals, each crystal grows rapidly and precipitates out, leaving behind a thinner, supercooled-water cloud.

(*c*) With moderate numbers of crystals, all the water is sublimated on to the crystals, but by that time they are large enough to have a significant falling speed. They therefore precipitate out and clear air is left. The falling crystals may either reach the ground as rain or snow or, more generally, they will evaporate in the drier air below the cloud.

Some experiments of Findeisen, recently repeated at Oxford, suggest that a growing ice crystal will itself generate new, and separate, ice crystals—conveniently thought of as " splinters ". It is also possible that real splinters may arise through mechanical breakage; and other ways have been suggested in which the presence of one ice crystal may give rise to others—and these, in turn, to others.

*The index numbers refer to the list of references on p. 9.

The existence of any such chain-reaction process may account for the apparent relative unimportance of the original rate of seeding, which has been noticed both by us and in experiments in other countries.

Applications of artificial nucleation.—The possible applications of this new technique may be summarised under three heads:—

(*a*) To produce rain where none would otherwise have occurred.

(*b*) To control rain—*e.g.* to cause it to occur earlier, or in other places, or to prevent the occurrence of torrential rain, hail and thunderstorms.

(*c*) To clear cloud.

These applications will be discussed in turn and we will describe our own experiments under each heading.

(*a*) *To produce rain.*—Seeding a supercooled cloud will always produce precipitation, unless the seeding is on such a scale that very large numbers of ice crystals are formed. It is not at all certain what rate of seeding would be required for this latter effect—it certainly depends upon the temperature and the nature of the cloud, and also upon the size of the ice pellets used. We have always used pellets about the size of peas, and generally rates of ten pounds or less per mile run. Except in the case of thin, very cold clouds—where a rate of 2–3 lb./mi. is apparently sufficient to convert the cloud to an ice-crystal cloud (see our experiment of August 16, 1949)—it seems that rates of much greater than 10 lb./mi. would generally be required. Provided that we seed at lower rates than this maximum, precipitation will always result. Normally the precipitation will continue until there is no cloud left, or until all the ice crystals have fallen out. In either case the amount of precipitation cannot be appreciably greater than the amount of water originally in suspense in the cloud. For all practical purposes this amount is trivial. To obtain any significant amount of rain it is necessary to have conditions in which the cloud is being constantly renewed, and in which, also, there is a constant supply of ice crystals.

These conditions may arise in two ways:—

(i) Where there is unlimited cloud—as, for example, when orographic cloud is being formed in air flowing over some obstruction. It is not known whether any chain-reaction process would be sufficient, after an initial seeding, to maintain precipitation indefinitely, or whether continuous seeding would be necessary. Probably the latter. If so it might be that a silver-iodide smoke, generated at ground level, might be an effective agent, as suggested by Langmuir and others[1]. Any such cloud would, of course, have to extend to levels where the temperature is appreciably below freezing. Experience suggests that whenever orographic cloud of such a nature exists in this country it is always raining, or snowing, already.

(ii) Where a direct consequence of the seeding is the production of a self-generating storm. At least two experiments have been reported[1 2] in which seeding with dry ice was followed by the development of a much larger cloud from which rain fell in appreciable quantities for some hours. On both occasions, however, conditions were very suitable for the development of natural storms, and it seems probable that the balance of stability was just tipped, either by the release of latent heat as the supercooled water turned into ice (Bannon[4]) or by the increased buoyancy due to the release of precipitation from the cloud, or both. A self-generating storm has never been produced in this country.

The necessary conditions are very critical, and it is probably true to say that the cloud must, in fact, be on the point of precipitating anyway. So that it is unlikely that rain, which would not have fallen otherwise, can be produced in this way.

(*b*) *To control rain.*—If it were possible to tell, at a sufficiently early stage, which cloud was going to develop into a thundercloud, seeding this cloud at the appropriate moment might possibly prevent the occurrence of a thunderstorm, replacing it, perhaps, by a longer period of less intense rain. In fact, however, thunderstorms develop very quickly, and it is extremely difficult for an aircraft to be in the vicinity of the right cloud at the right time.

Moreover, when studying the effect of a seeding, one can never know what would have happened had the seeding not taken place. In countries where thunderstorms are common it should be possible to carry out a rigorous investigation in this way; whenever a suitable cloud is found a decision whether to seed it or not is made by spinning a coin. Whether seeding takes place or not, the developments of the cloud are followed in exactly the same way. Only by some such expedient can the effects of seeding incipient shower clouds be studied.

Widespread and continuous seeding from the ground, by silver-iodide smoke or other means, would probably alter the whole character of convection weather and might well prevent thunderstorms altogether.

We have not made many attempts to control the development of cumulus clouds—mainly because of the impossibility, as we have pointed out, of interpreting the results. The two experiments which we have carried out both resulted in the clouds precipitating for a while and then dispersing from the base upwards.

November 3, 1947.—There were several large cumulus clouds with tops to about 12,000 ft. (temperature about 6°F.) and one or two had anvil tops. We chose one which was smaller than the rest and had no anvil top. In two runs through the cloud we dropped about 120 lb. of dry ice. After 30 min. the cloud had grown from about 11,000 ft. to about 14,000 ft. and an anvil had formed. However, practically every other cloud in the area had also grown and some had formed anvils. But from being one of the smallest ours was now as large as any save one. Slanting views showed that rain was falling. After 40 min. there was practically nothing left of our cloud except the anvil, from which some precipitation was still falling. There were no radar observations of this experiment.

August 30, 1949.—Cumulus clouds, without anvils, with tops to 15,000 ft. (temperature about 16°F.) were giving radar echoes. All these clouds were found to contain ice crystals. A somewhat smaller cloud, top 14,000 ft., which was not giving an echo was selected. This cloud was found not to contain ice crystals. In three runs over the cloud 50 lb. of dry ice were dropped. At first there was a slight lowering of the cloud top but after 10 min. there were signs that the top was becoming ragged and it had risen to its original height. At the same time a small echo was received by the ground radar station. Ice crystals were found in the cloud and rain was falling from it. After 45 min. the echo had gone, the rain had stopped, and there were no longer ice crystals in the cloud.

(*c*) *To clear cloud.*—It is necessary to distinguish between precipitating and non-precipitating supercooled cloud. It is our experience that if a supercooled cloud is precipitating there always exist within it large numbers of ice crystals. From what we have said earlier about the relative unimportance of the rate of seeding (perhaps because there is some process whereby the presence of one ice crystal produces large numbers of others) it seems probable that seeding an already precipitating cloud will have little effect—unless it is possible to introduce so many ice crystals at once that the cloud becomes, for the time being, an ice-crystal cloud. If it does so the precipitation should cease.

The cessation is almost bound to be only temporary since the fact that the cloud continues to exist, in spite of the precipitation that is occurring, indicates that vertical ascent of air is continuously renewing the cloud.

We have ourselves seeded precipitating cloud on two occasions:—

June 21, 1948.—Dry ice was dropped into a sheet of cloud whose top was at about 10,000 ft. and temperature about 22°F. The cloud covered a wide area, but radar echoes were being received only locally. The part of the cloud which we seeded was giving an echo. After seeding, the ground radar station reported that there did appear to be a clear lane through the echo where we had seeded—but the whole cloud sheet was breaking up and identification was difficult.

September 21, 1949.—Convergence into a trough was giving widespread cloud and local areas of rain. The cloud base was at about 6,000 ft. but very variable. The top of the first layer was at about 16,000 ft. with another layer, base at about 18,000 ft., above—but these two layers appeared to join up in places. We seeded from 16,000 ft. over a bright-band type of echo (temperature about 5°F.). Although the cloud we were ourselves in at the time of seeding appeared to consist entirely of ice crystals, the sun, when it was visible, was surrounded by a corona—indicating the presence above us of water drops. We seeded for about 10 miles at the rate of 8 lb./mi. No effects were observed either by radar or visually.

In the case of non-precipitating supercooled clouds, seeding will result in the production of precipitation and will often leave a cleared lane in the cloud.

It has been suggested that a path could be cleared in this way through which an aircraft could ascend or descend in icing clouds. However, in our experience these non-precipitating supercooled clouds are always shallow and never give rise to serious icing.

It is possible, of course, that supercooled fogs or low stratus clouds might be cleared by seeding—but these are quite rare phenomena in this country.

In spite of the fact that these experiments may have little "practical" value, they are well worth doing. For we believe that a study of the way in which a clearance, once formed, spreads through the cloud, and how it eventually fills in again (if it does) might give useful information on atmospheric processes—especially turbulence.

Unfortunately continuous sheets of non-precipitating supercooled clouds are suprisingly rare. During the past two years we have been able to experiment on only two—and in neither case were we able to make any detailed study of the effects of the seeding.

August 16, 1949.—There was a sheet of altocumulus cloud at 25,000 ft., about 500 ft. deep, temperature about −14°F. It was a pure-water cloud where we flew through, but virga was visible in one place in the distance indicating

the existence there of ice crystals. We flew above this cloud and seeded it at the rate of about 2 lb./mi. for 25 mi. Looking back, the effect of the seeding was quick and marked. Cumuliform heads rapidly developed along the line of seeding—each head being at first quite separate from the next, although seeding had been almost continuous. The line of cumulus showed very white against the general dark background of the rest of the cloud. The cumulus heads dispersed and the ice-crystal lane spread sideways for a while and then seemed to disappear. It did not seem that any clear lane was opened up in the cloud. Flying below the cloud later a magnificent halo complex was observed. Although it is certain that this complex arose from the cloud at 25,000 ft.—and not from a fairly extensive layer of cirrus at a much higher level—we cannot be sure that it was from the part of the cloud which we had seeded.

September 1, 1949.—A sheet of non-precipitating altocumulus cloud with top at about 15,000 ft. (temperature about 10°F.) and about 4,000 ft. deep was seeded at the rate of about 6 lb./mi. Unfortunately the whole cloud sheet was breaking up rapidly, and it was quite impossible to observe whether the seeding had had any effect or not. No radar observations were available.

The author has had described to him, and he has himself seen, on days of broken altocumulus cloud, instances of aircraft leaving contrails when in clear air, but, when passing through a sheet of cloud, leaving a clear lane. It is believed that this also is an example of the artificial nucleation of supercooled cloud. For if the contrail consists of ice crystals then, inside the supercooled cloud, these ice crystals will grow and precipitate out, leaving a clear lane through the cloud.

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ARTIFICIAL STIMULATION OF RAIN

In July 1949, Imperial Chemical Industries Ltd. decided that, unless substantial rain soon fell in the catchment area near Teesdale, production by certain factories on Teeside would be severely restricted owing to lack of water. I.C.I. Ltd. therefore were prepared to attempt artificial stimulation of rain by " seeding " suitable clouds with " Drikold ", one of their products, more commonly known as solid CO_2 or " dry ice ". With the authority of the Air Ministry a Wellington aircraft from Middleton St. George was adapted for the experiments, and arrangements were made for special forecasts to be issued by the Central Forecasting Office.

The main conditions regarded as suitable for the experiments were:—

(*a*) Clouds were to be cumulus in the developing stage, of about 10,000 ft. in vertical extent.

(*b*) Clouds must extend at least 3,000 ft. above the freezing level.

(*c*) Sufficient free water must be present in the cloud to liberate enough heat on freezing to promote further convection.

The table below gives the chief data relating to the three attempts that were made:—

TABLE I

Date	Time of seeding	Top of cumulus cloud	Air temperature at cloud top	Height of freezing level	Amount of " dry ice "
	B.S.T.	ft.	°C.	ft.	lb.
August 3	1723	10,000	−4	6,000	200
August 8	1703	10,000	−3	6,000	300
August 11	1350	8,000	0	8,000	300

On the first experiment, near Appleby, no upward growth of the cloud was observed, but a slight rain shower commenced within ten minutes of the seeding. No precipitation had previously been seen in the district that day, but, half an hour after the seeding, a ground observer near Richmond, Yorkshire, noted a moderate shower, with pronounced trailing virga, from an isolated cumulus cloud to the north. This may have been the cloud which was seeded.

The second attempt made to the east of Penrith was more successful (see photographs facing pp. 16–17). By 1711 B.S.T. the cloud top had risen about 500 ft. The Wellington descended rapidly; at 1723 cloud base had lowered from 3,000 ft. to 2,300 ft., and a heavy shower was falling. At 1730 the shower was of moderate intensity. No other precipitation was observed in the district.

Four minutes after seeding, on the third attempt, the cloud top had risen 200–300 ft. While flying at 4,000 ft. through the cloud six minutes later, very slight rain was experienced. At 1410, very slight rain was falling from the cloud (cloud base 2,000 ft.). This third attempt might have been more successful had it been carried out a few hours earlier, when clouds were in the developing stage and many of the tops were over 10,000 ft.

Soon after August 11 the water crisis on Teeside ended owing to the fall of natural rain, and the experiments were discontinued.

There are 40 to 50 stations which measure rainfall within about 30 miles of the location of these experiments. Returns from these stations were specially called for, and the daily amounts and the observers' comments of the time of the rain have been examined, together with the autographic records from Forest-in-Teesdale, Darlington and Durham with the following results:—

August 3.—No rain was recorded over a wide area, except a " trace " at one station two hours before seeding and a shower at another station about 25 miles away and 37 minutes after seeding.

August 8.—One slight shower may have been connected with the seeding, as recorded at Forest-in-Teesdale some 7 minutes after seeding. During the night after the seeding (which occurred at 1703) rain fell at many places within 30 miles.

August 11.—Most stations recorded no rain at all for this day. At Forest-in-Teesdale there was no rain apart from 0·01 in. about four hours before the seeding occurred.

The observer at Middleton-in-Teesdale (not far from Forest-in-Teesdale) stated " there was no obvious effect on the weather by artificial action on the three days mentioned above."

A CONCISE METHOD FOR RECORDING SYNOPTIC DATA

By A. J. WHITEN

In the course of a piece of work recently undertaken, it has become necessary to devise a code for recording synoptic events day by day, which, besides occupying a minimum of space, lends itself readily to sorting and classification for statistical purposes. As this code may possibly be of use to others with a similar problem, a brief account follows.

For purposes of analysis, the United Kingdom is divided into seven areas, roughly equal in extent. This is done by drawing a line from Spurn Head to Birkenhead, another from Thames to Severn, and one through Oxford and Southampton. The Scottish border and a line from Dundee to Oban separate north England, and the Highlands and Lowlands of Scotland. The remaining four districts are east, west, south-east and south-west. It is recognised that this division of the country is useless for forecasting purposes, but as hydrometeors cross the country with only limited regard for orographic features, approximate equality of the districts is the main consideration.

A code record is compiled daily for each district. Curvature of isobars is first represented by the use of large capital letters:—

A represents anticyclonic circulation;
B shows that the site lies in a col;
C represents cyclonic circulation.

This letter is followed by two suffixes, locating the nearest, or most significant, centres of high and low pressure, the direction being shown in compass points, the distance in hundreds of miles. High pressure is indicated by the upper suffix, low pressure by the lower one.

Movements of fronts are shown by the use of large figures, as follows:—

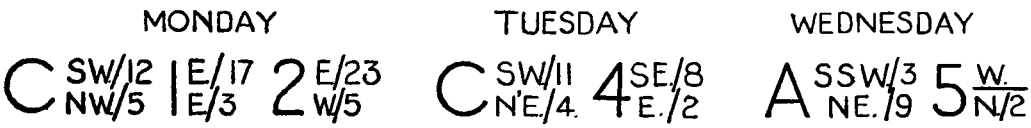
1 = warm front;
2 = cold front;
3 = warm occlusion;
4 = cold occlusion;
5 = stagnant front.

Each frontal figure is followed by two suffixes. After numbers 1 to 4, the upper suffix shows direction of movement by small capital letters, and time of passage over the centre of the district by figures, showing G.M.T. on the 24-hr. clock. The lower suffix indicates the alignment of the front at a standard hour (the same as that represented by the suffixes after the large capital letters). This is done by stating the direction of a normal from the centre of the district to the nearest point on the front at that hour. A figure is added to indicate the intensity of the front. In the case of stagnant fronts the procedure is slightly different as time of passage does not arise; in this case the upper suffix shows whether the district is situated in the warm or cold air mass with relation to the front.

Up to the present, the figure indicating the intensity of fronts has been the apparent difference in temperature between the adjacent air masses. This, however, is very difficult to ascertain with confidence from the data available to the investigator, which is limited to the *Daily Weather Reports*. It would probably be more satisfactory to indicate the change of pressure in millibars. The use of plus and minus signs should be unnecessary, as the character of the

front should indicate whether the pressure is rising or falling. The alternative possibility, of recording change of wind force and direction, would introduce a rather undesirable complication into what is, in spite of its somewhat fearsome appearance at first glance, really a very simple code to employ.

The following example, and its " translation ", will show how much space can be saved by its employment, quite apart from the fact that each detail is readily available for statistical classification.



The above would read as follows:—

" On Monday (at the standard hour) the district was situated in a cyclonic circulation. Effective high pressure was 1,200 miles to the south-west; low pressure, 500 miles to the north-west. At 1700 G.M.T. a warm front went through, moving eastwards. At the standard hour, the alignment of this front was from north to south. The approximate temperature difference across the front was 3°F. At 2300 G.M.T. a cold front went through, moving towards the east. Alignment north to south, temperature difference about 5°F.

" On Tuesday circulation was still cyclonic, high pressure 1,100 miles south-west, low pressure 400 miles north by east. At 0800 G.M.T. a cold occlusion went through to south-east, alignment north to south, temperature difference 2°F. approximately.

" On Wednesday the circulation was anticyclonic; high pressure south-south-west, 300 miles; low pressure, north-east, 900 miles. The district was under the influence of a stagnant front, situated to the north, aligned east to west, temperature difference approximately 2°F. The district was in the warm air mass in relation to the front."

It will be unnecessary to point out how much more can be deduced from such a record than is actually noted.

In the preparation of this code valuable advice, as to what was needed and what was impossible, was given by Cdr. G. L. Hogben.

RELATIONSHIP BETWEEN THE AVERAGE MONTHLY RAINFALL AND THE AVERAGE NUMBER OF DAYS PER MONTH WITH 0·4 in. OR MORE OF RAIN

By E. V. NEWNHAM, B.Sc.

The average number of days per month with 0·40 in. or more rain, referred to in this note as N, is sometimes included among meteorological statistics, *e.g.* in Admiralty " Pilots ", where it is taken to represent the number of days of " considerable rainfall ". It often happens that daily totals of rainfall, from which N could be obtained, are not published, and N is estimated from the mean monthly rainfall, R. The object of this investigation is to obtain rough relationships between N and R for temperate and tropical latitudes.

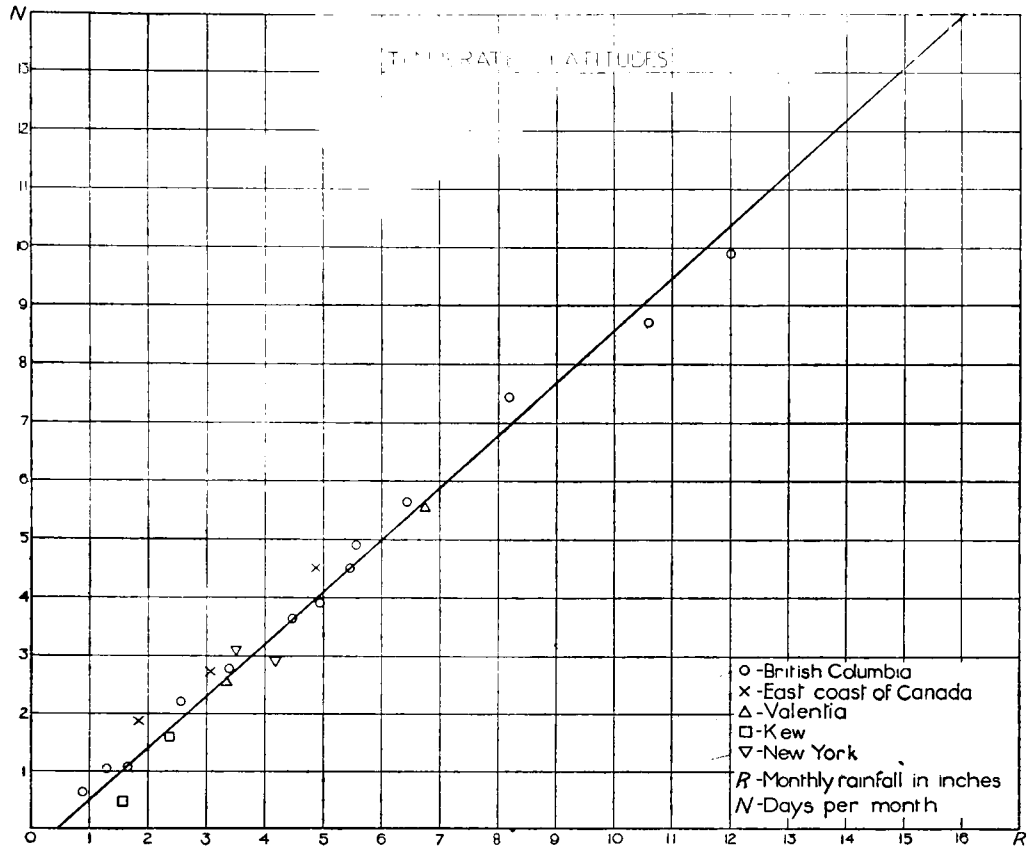


FIG. 1—THE RELATIONSHIP FOR TEMPERATE LATITUDES

The relationship for temperate latitudes is shown in Fig. 1, where N is plotted against R. For Kew, Valentia and New York the means of R and N for the months of greatest and least rainfall are shown, but for the coasts of British Columbia and eastern Canada it was found more convenient to group several stations of roughly equal average rainfall together and obtain monthly means

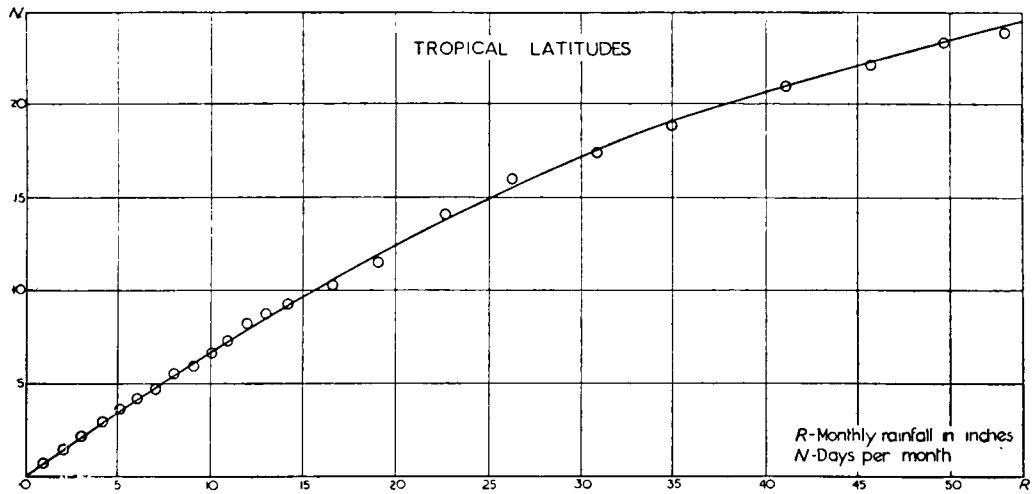


FIG. 2—THE RELATIONSHIP FOR TROPICAL REGIONS

for a relatively short period (5 yr.). It appears from the graph that

$$N = 0{\cdot}9\,R - 0{\cdot}4 \text{ approximately}$$

and that N obtained from this formula should generally be within a day or two per month of the correct value.

The relationship for tropical regions is shown in Fig. 2. Here each point is obtained by grouping together from among the monthly means those having about the same average rainfall, and averaging N and R for the group. The number of monthly means in a group averaged about 15, and the length of record used averaged about 22 yr., consequently each plotted point is on an average the mean of more than 300 pairs of observations of N and R. It will be seen that up to about $R = 10$ in. the relationship is very nearly $N = \frac{2}{3}R$, but that for higher values of R the slope of the graph steadily decreases. Since Fig. 2 does not show the amount of variation of N for a given R, and therefore does not show the amount of error to be expected when estimating N from R by means of the graph, the following table has been added:—

PERCENTAGE FREQUENCY OF ERRORS OF ESTIMATE OF N FROM THE GRAPH IN FIG. 2
(based on 252 monthly means)

Limits of R	Error of estimate (days per month)				
	0	1	2	3	4
	per cent.				
< 10 in.	79	21	0	0	0
10–20 in.	50	35	7	8	0
20–30 in.	20	23	46	11	0
30–40 in.	13	40	27	13	7
40–50 in.	26	53	21	0	0
50–55 in.	50	50	0	0	0

The stations used were Batavia, Fiji, Mauritius, Tulagi (Solomon Is.), Samoa, Fanning Island, Christmas Island, Colombo, and 36 stations on the coasts of India and Burma, which last provided all the monthly means with R more than 18 in.

METEOROLOGICAL OFFICE DISCUSSION

November 7, 1949. The present climatic fluctuation. By Hans W:son Ahlmann (*Geogr. J., London*, **112**, 1949, p. 165). Opener—Mr. R. F. Zobel.

Changes of climate of varying orders of magnitude are known to have occurred many times in the past, as, for example, in the formation and disappearance of ice ages.

A deterioration of climate occurred in the higher northern latitudes about 1200–1300 A.D. Over the last 100–150 years, however, there are many indications that there has been a noteworthy amelioration. This amelioration is referred to as the present climatic fluctuation.

Climatological evidence of the present fluctuation.—The longest series of temperature records comes from Holland. It dates from the beginning of the eighteenth century. By using 30-year overlapping means, the records

show that the winter temperatures decreased from the first half of the eighteenth century to a minimum in the beginning of the nineteenth century. Since then an increase has prevailed to this day. Changes at other seasons are small.

Similar analysis of temperature records for places in England, Sweden, Norway, Denmark, Finland and the U.S.S.R. shows the same general trend, but the most outstanding increase of temperature is recorded in winter at Spitsbergen, where mean winter temperatures, computed in 10-year overlapping means, rose by more than 7°C. between the periods 1908–17 and 1928–37.

Lysgaard has given a summary of the thermometric evidence of the recent fluctuation by stating that both winter and summer temperatures have shown an appreciable increase over great parts of the earth, especially the temperate and arctic zones, whilst over the tropical and subtropical zones a decrease has taken place. This view is also taken by Ångstrom.

The immediate cause of the improvement of climate in high northern latitudes is undoubtedly increased atmospheric circulation, resulting in increased advection from low to high latitudes. Since the area of the tropics is large compared with that of high latitudes, increased circulation would be expected to produce a small fall of temperature in low latitudes and a comparatively large rise in high latitudes, which is broadly the effect observed during the recent climatic fluctuation.

Increased circulation also affects the distribution of rainfall and changes in this respect have also been observed. Though rather variable from place to place the precipitation over Norway as a whole has increased by about 10 per cent. in the last 100 years, whilst there has been a similar trend in Sweden. Once again Lysgaard has summarised the changes in global distribution by stating that from the period 1881–1910 to the period 1911–40 precipitation has increased throughout the arctic and much of the temperate zone, whereas there has been a decrease in tropical and subtropical regions with the exception of the monsoon regions of south-east Asia. This statement is supported by the fact that there has been a considerable lowering of the level of lakes in east Africa, whilst the Sahara is tending to spread slowly southwards.

It is not yet possible to say with certainty that the climatic fluctuation is world-wide, but the larger the number of places examined becomes, the greater becomes the evidence. The main gap in the evidence occurs in the southern hemisphere, notably in the Antarctic. If it can be shown that this area is affected also, then it can be said that probably all regions have been affected, in which case it seems most likely that the fundamental cause of the fluctuation of climate must be looked for in changes of solar radiation, possibly connected with sunspots.

Much work remains to be done before it will be possible to be certain of the causes of the fluctuation, but this is the first fluctuation in the endless series of past and future climatic variations in the history of the earth which can be measured, investigated and possibly explained. It is, therefore, important to ascertain in what other ways the climatic change has been manifested and has thus provided confirmatory evidence.

Glaciological evidence.—Thorarinsson has made an extensive study of glacier variations and comes to the conclusion that " the marginal variations of the glaciers in recent centuries have in all probability been more or less

concurrent all over the world ", whilst Matthes says " glaciers in nearly al parts of the world receded irregularly during the last 60 years, but especially rapidly during the 1931–40 decade ".

The reduction in glacier volume in the North Atlantic area began about 200 years ago, at which time the local glaciers reached their maximum extent in historical times, perhaps even in post-glacial times. All the glaciers in recession are losing more material by ablation than they receive by accumulation of snowfall. This means that the rising temperature has been sufficient to overcome the tendency to create glaciers through the increased precipitation.

A plate will be published in the next number of this Magazine giving photographs of the Åbrekke glacier near Jotunheim in south-west Norway, taken in 1869, 1933 and 1946, which shows a very marked recession.

Oceanographical evidence.—Investigations in various districts of the northernmost Atlantic show that there has been an increase of sea temperature and also of salinity. This warming has resulted in a reduction of the thickness of the ice in the Polar Sea. Pack-ice is also less extensive in general. In fact, the shipping season for Spitsbergen coalfields is now about seven months as against three months at the beginning of the century.

Biological evidence.—The increased warmth of northern waters has caused fish, notably the common cod, to migrate northwards. At the beginning of the century cod was rare in Greenland waters. Now it is abundant and has become practically the staple diet of the Greenlanders.

Birds and insects have shown similar tendencies as illustrated by the fact that species common in Iceland are being slowly replaced by more southerly species.

Prospects for agriculture have become much improved in Sweden and Finland due to the increased growing period which amounts to an additional 2–3 weeks per year. This has also affected the northern forests in such districts as Scandinavia, Finland and Alaska where the timber-line is spreading northwards, whilst the trees show increased growth and a greater fertility.

Eustatic evidence.—The part played in the rise and fall of sea level by repeated release and absorption of water in ice-caps is known as glacial eustasy.

It might be expected that the present melting of the glaciers would raise the level of the oceans. This is in fact the case, though measurements in different parts of the world indicate that the rise has only been of the order of 1 mm. per year. This suggests that the main higher-level ice-caps of Greenland and Antarctica, which together contain more than 90 per cent. of the world's land ice, cannot be melting at the same rate as the local glaciers examined.

Mr. Zobel said that he felt the greatest interest in the paper was in the fundamental cause of the climatic fluctuation, since if this could be discovered, the bare possibility of scientifically sound long-range forecasting occurs. He mentioned briefly the views of Ångstrom, Willett and Brooks, none of whom inclines to the view that climatic fluctuations are caused by changes in the intensity of the long-wave radiation emitted by the sun. Both Ångstrom and Willett consider that such changes are probably due to variations in the ultra-violet band which affect the distribution of pressure and temperature at high levels of the atmosphere and therefore influence the pattern of the general

Photo by R.A.F.

1703 B.S.T.

Photo by R.A.F.

1704 B.S.T.

CLOUD FOR DRY ICING

(see p. 10)

[*To face p.* 16

Photo by R.A.F.

1711 B.S.T.
CLOUD FOR DRY ICING
(see p. 10)

Photo by R.A.F.

1723 B.S.T.
CLOUD-RAIN AFTER DRY ICING
(see p. 10)

Photo by R.A.F.

1723 B.S.T.

Photo by R.A.F.

1730 B.S.T.

CLOUD-RAIN AFTER DRY ICING

(see p. 10)

Photo by R.A.F.

1730 B.S.T.

Photo by R.A.F

1730 B.S.T.

CLOUD-RAIN AFTER DRY ICING

(see p. 10)

circulation. On the other hand Brooks considers that minor fluctuations of climate are probably inherent in the atmosphere itself, or in its interaction with the oceans, owing to some process initiated almost by accident in the constant turmoil of depressions and anticyclones, but which, once begun, automatically increases intensity until it becomes unstable or is reversed by some other accident. This view was enlarged upon by Dr. Brooks himself in the discussion which followed the opener's remarks.

The Director pointed out that variations in annual means greatly overshadow the general rise in temperature. He remarked that it is important to take the broad overall view of climatic statistics, since a fall of mean annual temperature of the order of 7–8°C. would be sufficient to produce an ice-age.

Mr. Marshall showed lantern slides illustrating temperature changes in London over the past 100 years. He suggested that the increased winter cyclonic activity in the far north may be associated with a westward extension of the Russian anticyclone, which, when centred over south Scandinavia, would give severe winters in London, as for example in the period 1939–41. His data showed that the most noticeable change had been a fairly steady increase in spring temperatures when computed in 10-year overlapping means. Corresponding winter temperatures showed a similar trend from the period 1899–1908 to the period 1929–38, but during the last decade they had decreased.

Dr. C. E. P. Brooks said that there is no real evidence of a variation of solar radiation during the Christian era. He thought that the atmospheric circulation might not be self-adjusting as generally supposed. During a period of extensive ice in the arctic the " surface pool of cold air " is extensive but shallow, with a strong inversion and warm air above it. This weakens the circulation at 10,000 ft. and through that the surface circulation, and allows the cold conditions to persist. When the arctic is mild the " surface pool of cold air " there is less extensive and less stable; the air above it is relatively cold and a strong circulation is maintained. The Icelandic low is deep and maintains a flow of warm air and water into the arctic. Hence two types of atmospheric circulation are possible under existing conditions of radiation, both persistent, and exceptional conditions are required for a transition from one to the other. Such transitions occurred about the 4th and 11th or 12th centuries. If the present climatic trend continues for another 25 years or so, we may have a third transition, with a return to the warm climatic conditions of Saxon England.

Miss Lewis said the 20-year overlapping means of winter temperatures for Oxford and other places in western Europe showed a fall in the last 10 years, and asked if more recent data than those given by Ahlmann were available for the arctic.

Professor Manley agreed with Miss Lewis that the Oxford record showed a fall of temperature in the winter but the spring had remained warm. The decade 1771–80 with warm summers and cold winters, shown in Dutch and English records, was similar to the last 10 years. It is of interest to compare this fluctuation with other occasions of sudden glacial recessions, notably about 1739, in order to try and forecast its persistence or otherwise. He stated that it is apparent that the existing overall variations could be explained by variations of the vigour of the atmospheric circulation, but more evidence, not only from the past but also from regions such as the North Pacific, is needed in order to indicate the degree of persistence one way or the other.

Mr. Lamb said that it would be wise to admit the possibility of variations in solar energy affecting climate even though this involved the introduction of an " unforecastable " factor. He considered that it might be possible to use data relating to the extent of ice and snow cover, as well as oceanographic data, to predict the broad circulation patterns likely to develop. As an example, he mentioned the fact that the observed warming of the Norwegian Sea over the past 20–30 years has led to an intensification of the thermal gradient off east Greenland. Depressions centred near south Greenland have therefore tended to turn further north, thus leaving room for anticyclones to form over Scandinavia, so producing cold winters over the British Isles concurrent with the highest sea temperatures ever known in the Norwegian Sea.

Cdr. Frankcom suggested that the vast amount of synoptic observations from ships might provide valuable evidence of the global extent of the present climatic fluctuation.

Mr. Bull said that he had found evidence that the rate of climatic change at Jan Mayen had slowed down in the last decade. The mean winter temperature for 1935–44 there was only 0·4°C. above the 1912–30 average, whereas the 10-year means terminating in the 1930's were 2–3°C. above. The Spitsbergen observations were unfortunately too broken in the war years to be of any use.

Dr. Sutcliffe said that he could see no reason why physical meteorologists believe that climatic change must, almost obviously, have an extra-terrestrial cause. He considered that it is quite possible for climate to be largely determined by variations in extent of the ice-caps. These ice-caps might very well grow as a result of snowfall near their boundaries, but eventually the boundaries would be so far displaced as to leave dead ice behind, which in time might wear thin by evaporation or other process, so permitting a sudden jumping of depression tracks to new open waters and a rapid thaw in the resulting westerlies.

Mr. Kirk remarked that it is improbable that changes of climate can be explained without taking the oceanic circulation into account.

Dr. Carruthers referred to the great economic implications which arise as the result of the northward migration of marine animals. In this respect it is important to learn whether the peak of this migration has been passed. Contrary to German opinion, which placed the peak year as 1938, the latest Canadian researches based on studies in Hudson's Bay indicate that the peak has not been passed. He also pointed out that relations between atmospheric circulation and the location of ocean currents such as the Gulf Stream are extremely complex. He felt that the integrated evidence of climatic change provided by agriculture was more reliable than records of sea temperature.

Mr. Gloyne emphasised the reliability of agricultural data in this respect, and remarked that a rise in mean winter temperature of 1°C. would be sufficient to permit grazing in southern England at all times of the year.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Royal Meteorological Society on November 16, 1949, Mr. E. Gold, Vice-President, in the chair, papers were read by Mr. F. Pasquill on a portable apparatus for the study of temperature and humidity profiles near

the ground[1]* and on estimates of the amount and diurnal variation of evaporation from clay pasture in spring[2] and by Mr. C. S. Durst on the calculation of departures of wind from the geostrophic value by the use of constant-height balloons[3].

Mr. Pasquill's instrument is designed to measure the temperature and humidity at six levels, 25, 37·5, 50, 100, 150 and 200 cm. above the ground. It consists essentially of six horizontally-mounted modified Assmann psychrometers with thermocouple elements to facilitate distant reading. The elements are placed in horizontal tubes leading into a hollow aspiration mast about seven ft. long. Air is drawn past the elements by a fan at the top of the aspiration mast. The apparatus is made as far as possible of standard moulded-plastic tubes. Shields were provided to reduce radiation errors and the bushes were inserted in the side tubes to give a constant rate of aspiration of 2·5 m./sec. in all of them as is necessary owing to the variation of the psychrometric " constant " with rate of airflow past the bulb. The thermometric elements were deliberately given substantial thermal inertia and the lag coefficient was 1 minute for the wet and 2 minutes for the dry bulb. Some examples of temperature and humidity profiles were shown, giving very smooth curves.

Mr. Pasquill drew attention to an evaporation formula used by Thornthwaite and Holzman[4] but the validity and limitations of this had only recently been directly tested. This formula, applicable only to the flow of an adiabatic atmosphere over an aerodynamically rough surface is

$$E = \rho \frac{K^2 (q_1 - q_2)(u_2 - u_1)}{(\log_e z_2/z_1)^2}$$

where E is the rate of evaporation, q_1, q_2 and u_1, u_2 are the specific humidities and wind velocities at heights z_1, z_2, ρ is the air density and K is Karman's " constant ", here of magnitude 0·4.

Appealing to a previous demonstration of " virtual adiabaticity " near the surface in non-adiabatic conditions, Mr. Pasquill then applied a simplified form of the above formula in evaluating evaporation from hourly observations of wind velocity and vapour pressure at 50 cm. and 25 cm. He showed curves of wind velocity, U_{50}, vapour-pressure difference, $e_{25}-e_{50}$, and the computed values of E in 10^{-5} gm./cm.^{2}/sec. taken over an exposed clay pasture near Cambridge from May 7 to 13, 1947. Both velocity and vapour-pressure difference showed a marked diurnal variation with maximum values about midday so the evaporation, proportional to their product, showed an even more marked diurnal variation. Negative values of the vapour difference and consequently of the evaporation occurred over several hours on some nights and during these periods dew was observed to form. He considered that his method gave the evaporation with an accuracy of mainly 10 per cent. rising to 20 per cent. in the unstable conditions of midday. The total daily evaporation found by integrating the curves varied between 1·4 and 3·6 mm. Mr. Pasquill concluded by pointing out that it was essential to employ hourly values of wind velocity and vapour-pressure difference for computing evaporation, and that the use of mean daily values in the formula would give an underestimation of about 50 per cent.

*These index numbers refer to the list of references on p. 21.

Dr. Penman said he was considering the installation of a rather similar apparatus at Rothamsted, but he was using unaspirated elements and varying the psychrometric constant to suit the ventilation as he thought aspiration at 2·5 m./sec. would bring in air from levels above and below the desired one. He went on to question several aspects of the theory of turbulence in its application to evaporation such as the assumed constancy of shearing stress and of Karman's " constant ". Evaporation from tanks did not agree with Pasquill's results.

Prof. Sheppard said that if tank evaporation results did not agree it was because tanks were not the same as the ground. He emphasised that the turbulent-flow formulae were really empirical.

Mr. Lapworth would like to see the formula tested by installing Pasquill's apparatus over a tank, and also some method of using it without such frequent observations.

Dr. Glasspoole said evaporation measurements at Valentia in 1930 showed evaporation going on throughout day and night, the night value being about half that during the day. He pointed out that water engineers would like a higher order of accuracy than 10 per cent. which was a large error for evaporation from a reservoir.

Dr. Robinson said that at Kew there was a near copy of Pasquill's apparatus close to an evaporation tank, and it was found that the tank gave the same value of evaporation in daylight so long as the grass was in good condition, but at night the tank goes on evaporating when the ground appears to stop.

Dr. Sutcliffe said it would be useful if the fall of dew, on which there was little information, could be given from Mr. Pasquill's curves. He thought the formula rather doubtful as he was sure dew would fall at night or evaporation take place in a flat calm, but perhaps Karman's constant became indeterminate then.

Mr. Pasquill in reply said the evaporation formula does not apply to tanks, over which there was stable air. With regard to aspiration errors of the apparatus he described trials which satisfied him that there was no significant sucking of air from other levels. Though the observational justification of the formula had so far been confined to evaporation, as distinct from condensation, he saw no reason why it should not apply to the latter within the limits of departure from adiabatic conditions and so gives dewfall by integrating the appropriate sections of the curves.

Mr. Durst said that, following a suggestion by himself and Prof. Sheppard, balloons carrying constant-height apparatus were followed by radio direction finding on seven occasions in 1943 and 1944 in order to compare the measured departure of the wind from the geostrophic with the departure to be expected by calculation from the observed acceleration. The balloons were made to follow a predetermined pressure level about 400 or 500 mb. by controlling the escape of gas or by jettisoning sand or fluid. The departure is, theoretically and neglecting friction, a vector to the left of and at right angles to the acceleration and having a proportion $1/2\ \omega \sin \phi$. The horizontal acceleration was measured from the observed track of the balloon and the term in the total acceleration arising from the vertical component of air motion was determined by using the variation in wet-bulb potential temperature at the balloon to give the vertical

component and by obtaining the vertical wind gradient from the routine soundings. From values of the total acceleration so obtained corresponding theoretical values of the geostrophic departure of the wind were calculated and compared with geostrophic departures calculated from a comparison between the routine soundings at Larkhill, Fazakerley and Downham Market with the geostrophic winds given by specially drawn contour charts. One of the flights had been omitted from consideration because the balloon passed through a front. Agreement between the calculated and computed departures was good in both direction and magnitude. Another method of finding the total acceleration by constructing trajectories from the 500-mb. contour charts did not give satisfactory values of the geostrophic departure possibly because the trajectories had to be smoothed over 36 hours. This suggests that geostrophic departures are not associated with major depressions and anticyclones but with small-scale irregularities. The balloon tracks were also used to find eddies in the wind and gave evidence of fluctuations of wind of the order of 3 or 4 kt. from one half-hour to another.

Prof. Sheppard, Dr. Sutcliffe, Mr. Matthewman, Mr. Craddock and *Dr. Robinson* contributed to the discussion in which questions were asked about the balloon which floating with the air managed to pass through a front and the relation of the eddies to deviations from the geostrophic wind. Mr. Durst replying, said he thought vertical motion of the balloon relative to the air carried it through the front and that the eddies were short-period affairs compared with the geostrophic deviations which were measured over hours.

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3. DURST, C. S. and GILBERT, G. H.; Constant-height balloons—calculation of geostrophic departures. *Quart. J. R. met. Soc., London*, **76**, 1950.
4. THORNTHWAITE, C. W. and HOLZMAN, B.; Measurement of evaporation from land and water surfaces. *Tech. Bull. U.S. Dep. Agric., Washington*, No. 817, 1942.

OFFICIAL PUBLICATION

The following publication has recently been issued:—

METEOROLOGICAL REPORTS

No. 3—Theoretical aspects of pressure-pattern flying. Compiled by J. S. Sawyer, M.A.

The techniques of pressure-pattern flying apply meteorological knowledge to air navigation. The most important methods (*a*) compute drift from radar altimeter observations, (*b*) enable flights to be made with a constant heading of the aircraft, and (*c*) indicate tracks which are quicker and more economical than the direct route.

In this report the theoretical basis of these methods is explained and the relevant meteorological factors are examined in detail. Particular attention is given to the accuracy which may be expected in pressure-pattern navigation and to the limitations to which the methods are subject.

LETTERS TO THE EDITOR

Frequency distribution of wind speed in synoptic reports

One of the changes in the code for synoptic reports of surface observations, about which there was most discussion and difference of opinion in the meetings of the Commission for Synoptic Weather Information at Paris in 1946, and Toronto in 1947, was the provision of two figures for wind speed.

I thought, therefore, it would be interesting to see how the values of wind speed (in knots) now published in the British Section of the *Daily Weather Report* were distributed. Reports are published for 61 stations for the four principal hours of observation, 0000, 0600, 1200 and 1800 G.M.T. The values are obtained from anemometers except for ten stations where they are estimated with the same aids as those used when the force was estimated on the Beaufort Scale. Five stations do not report at 0000 G.M.T. and there were a few other omissions.

I prepared frequency tables from the values in the 11 *Daily Weather Reports* for October 18–28, 1949, one table for the anemometer stations (A.) and another table for the non-anemometer stations (N.A.). They are reproduced below up to 40 kt. There were a few observations above 40 kt. but not enough to warrant extension of the tables. The period began with a deep depression and general gales and ended with an anticyclonic ridge and general calms and light airs. The range of speeds was therefore a wide one.

TABLE I—FREQUENCIES OF WIND SPEED, OCTOBER 18–28, 1949

A. = anemometer station values
S.A. = smoothed anemometer station values
N.A. = non-anemometer estimates

Speed	A.	S.A.	N.A.	Speed	A.	S.A.	N.A.	Speed	A.	S.A.	N.A.	Speed	A.	S.A.	N.A.
kt.				kt.				kt.				kt.			
0	116	116	8												
1	19	33	1	11	56	104	3	21	30	46	2	31	10	16	—
2	50	41	14	12	117	96	2	22	40	42	—	32	14	12	—
3	55	52	3	13	78	87	30	23	43	39	—	33	5	8	2
4	50	62	3	14	68	88	—	24	31	38	12	34	2	7	—
5	87	73	32	15	127	85	1	25	48	36	—	35	15	7	—
6	74	83	7	16	61	77	5	26	31	30	—	36	4	6	2
7	91	94	6	17	47	68	1	27	15	23	2	37	2	4	8
8	118	110	5	18	94	65	3	28	19	20	—	38	4	3	—
9	102	115	36	19	32	59	10	29	11	19	—	39	2	2	—
10	175	120	5	20	85	57	—	30	36	20	7	40	2	2	5

There are some features in the tables which leap to the eye and are not difficult to explain. But there are others which are less obvious.

For the A. stations the principal feature is the preponderance of the tens and fives. The average frequency of occurrence of one of the ten digits is 195. But the frequency of the noughts (excluding the calms) is 298 and of the fives, 277. The greater number of noughts than of fives is due to the fact that the maximum frequency is near to 10 kt.

The frequency of occurrence of the other digits is as follows:—

Digit	1	2	3	4	6	7	8	9
Frequency	115	221	181	151	170	155	235	147

It is difficult to see a satisfactory explanation of the outstanding maxima at digits 2 and 8. There is, on the whole, a preference for even numbers. The total for the even digits is 777 and for the odd 598; if 0 and 5 are included the totals are 1075 and 875 respectively.

Of individual values, apart from the noughts and fives, the most outstanding is the frequency of 18 kt., *viz.* 94, more than double the frequencies of 17 or 19 kt. and greater even than the frequency of 20 kt. Outstanding also is the low frequency of 1 kt., but this is perhaps less surprising than the equality of frequencies of 2, 3 and 4 kt.; the standard anemometers are not very sensitive at these low speeds and an uneven distribution might have been anticipated.

The fact that the frequency of calms does not fit into the series is not surprising. Calms form a quite separate category independent of the unit used, whereas the other frequencies would be doubled if metres per second were used in the classification instead of knots.

Clearly many of the reports of 10 kt. should have been of 9 or 11 kt. and some 8 or 12 kt., and similarly for the other tens and the fives. In order to see what the correct distribution of frequencies should be, I have tried smoothing the A. series by several formulae. The best appears to be $(a+2b+3c+2d+e)/9$. This is the same as forming a new series by the formula $(a+b+c)/3$ and then smoothing the new series by the same formula $(a+b+c)/3$. The first smoothing eliminates the error due to preference for even numbers and part of the error due to preference for noughts and fives. The second smoothing practically completes the elimination of the latter error. The smoothed values are given under the heading S.A. The frequency of calms is not used in deriving the smoothed values. The first value is derived by giving b and c the frequency of " 1 ", a and d the frequency of " 2 " and e the frequency of " 3 ". For the second value, a and b both have the frequency of "1 ". The smoothed frequencies when plotted, lie fairly well on a smooth curve. Thus, statistically, the reports provide a fair representation of the distribution of wind speed. But synoptically they fail to provide the sound basis for close investigations which the protagonists of " two figures " for wind speed hoped. To achieve that, observers must discontinue the facile throwing of nines and ones to zero and of fours and sixes to fives.

The values for the N.A. stations congregate about the speeds at a height of 10 m. corresponding with the Beaufort numbers. This is broadly what was expected, though it was hoped there would be a substantial number of reports midway between these equivalents. E. GOLD

8 *Hurst Close, London, N.W.*11, *November* 3, 1949

[Similar results have been reported for other measurements, see Yule, G. U. and Kendall, M. G., An introduction to the theory of statistics. 13th edn. London, 1947, p. 86.—Ed. *M.M.*]

Radio-sonde ascent into cumulonimbus cloud

At the 2100 G.M.T. routine sounding on July 16, 1949, the radio-sonde launched from Camborne entered a cumulonimbus cloud and had an abnormal rate of ascent from 800 mb. to 350 mb.

The normal rig, consisting of a 500-gm. balloon, parachute, radar reflector, and radio-sonde transmitter was used. The balloon was inflated to give a free

lift of 3,400 gm. which would normally have given a mean rate of ascent of 1,200–1,300 ft. min. from the surface to 400 mb. The balloon was launched at 2000 G.M.T., and at that time the weather was cloudy with a moderate shower of rain. The cloud was 8 oktas cumulonimbus with a ragged and ill-defined base.

The rates of ascent for each 100-mb. layer from the surface to 300 mb. were:—

Layer	Surface–900 mb.	900–800 mb.	800–700 mb.	700–600 mb.	600–500 mb.	500–400 mb.	400–300 mb.
			ft./min.				
Rate of ascent	929	1454	1971	1673	2095	3397	1483

The heights obtained from the radar set confirm these rates of ascent. From 350 mb. to the burst at 98 mb. the rate of ascent was normal.

The temperatures obtained from this sounding are probably too warm between 600 mb. and 400 mb. because of the excessive rate of ascent and the consequent lag in the temperature unit. Between 400 mb. and 370 mb. the lapse rate recorded was 10·2°F./1,000 ft., and this is also considered to be due to the lag in the temperature unit.

G. A. JEFFREY

Kehelland, Camborne, Cornwall, August 18, 1949

Flight through cloud funnel of waterspout

During March 1949 a Harvard aircraft sighted a waterspout off the north-east corner of Singapore Island and deliberately flew through the cloud funnel. Unfortunately the observer did not report the fact at the time and the value of his observations is reduced by the lapse of six months before being recorded. However, in view of the rarity of such observations they are detailed below:—

Observer—F/Lt. Brain, Far East Communications Squadron.

Position—Over sea just off the eastern tip of Pulau Ubin, an island off the coast of north-east Singapore.

Time—0130 to 0230 G.M.T. March 14, 1949.

Weather—Cloudy, scattered showers, none appearing to be heavy or of any great extent. Main cloud base 2,000–3,000 ft.

The pilot was flying at 1,500 ft. when his attention was drawn to a cloud darker than the rest with cloud base about 1,200 ft. From this cloud the funnel of a waterspout was already to be seen meeting the sea surface. The pilot descended to 600 ft. From this position he estimated the diameter of the spout as 3–5 ft. where it met the sea and about 70 ft. at his level, widening gradually as it met the cloud base. The two ends of the funnel were relatively fixed while the middle writhed convulsively. Flying in clear air at 600 ft. turbulence was light and the funnel appeared to be totally composed of cloud. There was no precipitation at the time.

The pilot entered the cloud funnel at 600 ft. and for a short period the aircraft was completely enveloped. There was no appreciable increase in turbulence caused by passing through the cloud funnel and no apparent precipitation, nevertheless the aircraft emerged wet all over. On turning back to look at the funnel a few seconds later, it had apparently been unaffected by the passage of the aircraft.

The observer could not remember any facts about rotation or disturbance of the sea surface.

Weather observations at Changi at the time gave large cumulus but no showers until 0935, though thunder was first heard at 0915 that day.

P. E. PHILLIPS

Changi, Singapore, September 29, 1949

Lightning display at Ramsgate

The display of lightning, which I observed in the vicinity of Ramsgate between 1930 and 2030 G.M.T. on September 23, 1949, was, I think, unusual for this country. The centre of the storm lay to the south-west of Ramsgate and moved northwards. The sky was overcast with medium and high cloud and only towards the end of the period did low cloud at about 3,000 ft. develop. A few drops of rain fell intermittently.

At intervals of a few minutes a lightning stroke appeared from the south-west or west at an angle of about 40 degrees from the horizon. Most of the strokes lengthened to the zenith by, what seemed to be, a series of discrete steps, while branches from both sides of them moved outwards and lengthened in jerks. One stroke to the south-west did not lengthen to the zenith but branches sprang from it radially increasing in length in a similar way. Owing to the poor vertical visibility the illumination of the discharges was not so intense as to hinder me from observing them. The thunder associated with the discharges was heard first overhead at about 10 sec. after the flash was seen and was not loud. When later the low cloud developed only sheet lightning could be seen.

J. E. BELASCO

Harrow, October, 1949

[The phenomenon seen by Dr. Belasco appears to have been the rare phenomenon " rocket lightning " as described by Simpson (*Proc. roy. Soc., London,* A, **111**, 1926, p. 66) and Humphreys (" Physics of the air " New York and London, 3rd edn. 1940, p. 368). The storms of September 23 were particularly violent over north-west France. According to an article in *Figaro* hailstones weighing 650 gm. fell near Lisieux, Normandy.—Ed. *M.M.*]

NOTES AND NEWS

The Bilham humidity slide-rule, Mk. III

As was foreshadowed in an article by Mr. R. H. Collingbourne in the *Meteorological Magazine*, November 1948, a new model of the humidity slide-rule has been designed in order to furnish values of relative humidity and dew point with respect to saturation over water at all temperatures. The opportunity has been taken to extend the scales to very low temperatures so that the new slide-rule will be able to handle not only surface observations made in high latitudes but also upper air observations made by aircraft or by radio-sonde. The new rule will be known as Mk. III and will replace the earlier models Mk. I and Mk. II. Production is in hand and we hope to publish an article by Mr. E. G. Bilham giving full details in an early issue of this Magazine.

Photographs for new International Cloud Atlas

A small committee was formed by the International Meteorological Organization to produce a new International Cloud Atlas, with M. A. Viaut, Director of the French Meteorological Office, as President. The present Atlas was first published in 1932 and reprinted in 1939. The committee had its first meeting at Paris in August 1949.

The selection of photographs taken from the ground to illustrate the new Atlas is nearly complete, but there are still some gaps to be filled in respect of certain special forms. A recent circular letter from the President of the Committee asks for photographs taken in tropical and polar regions, and also for illustrations of special forms such as:—

Nacreous clouds
Luminous night clouds
Clouds produced by fires, volcanoes, waterfalls, etc.
Fog and mist
Phenomena due to sand, dust, or drifting snow
Condensation trails, artificial rain, artificial dissipation of clouds or fog
Clouds of insects (*e.g.* locusts)
Optical phenomena in clouds (haloes, coronae, etc.).

Photographs procured by unusual methods such as whole-sky photographs, infra-red, radar, V-2 rockets, etc., are also wanted.

The date, time and place of photographs should be noted, also the direction and approximate elevation of the photograph, and descriptive notes on the clouds and on any related feature of interest would be useful. Notes can conveniently be written on the backs of the prints, provided that nothing shows through to the other side. Enlarged prints are best, and obviously only photographs of a high technical standard have any chance of inclusion in the Atlas.

Colour photographs, on films or plates, would be particularly appreciated. If possible the size should be larger than the standard 24×36 mm.

The selection of cloud photographs from the air (or of photographs from mountains of clouds below the observer) has not yet been carried out. Though the number of cloud photographs from the air is now large, there is still a difficulty in finding suitable illustrations of some forms, especially of high clouds and altostratus. There is a natural tendency to concentrate on the more striking cloudscapes, so that clouds with poorly defined tops, and smooth or featureless layers which are not easy to photograph cannot yet be adequately illustrated. Whenever it is technically possible in such cases to obtain a photographic representation of what the observer sees, the result would be of scientific value even if it looks featureless.

Photographs are asked for taken from above, from below and from the side of clouds, at various angles, *e.g.* vertical, inclined and horizontal.

Photographs can be sent to me at the Central Forecasting Office, Dunstable, Beds., for forwarding to the Committee, and in the case of photographs taken over or near the British Isles, western Europe or the Atlantic, I can add the notes on the synoptic situation and the vertical atmospheric structure, which

are asked for in the circular letter. They are wanted by March if possible, and at latest by the time the Committee meets next summer, probably in June.

C. K. M. DOUGLAS

Frequencies of tropopause temperatures over Larkhill from June 1945 to December 1947

The frequencies of different tropopause temperatures over Larkhill given in the table below were extracted from summaries held in the Climatological Division.

SUMMARY OF TEMPERATURES AT THE TROPOPAUSE FOR LARKHILL
JUNE 1945 TO DECEMBER 1947

Temperature	Dec.–Feb.	Mar.–May	June–Aug.	Sept.–Nov.
°F.		*Number of occasions*		
−109, −108	1			
−107, −106	1			
−105, −104	1			
−103, −102	4			1
−101, −100	8			
−99, −98	13	1		3
−97, −96	14			9
−95, −94	15	1		12
−93, −92	26	3		11
−91, −90	28	9	2	20
−89, −88	38	10	2	37
−87, −86	38	18	2	32
−85, −84	49	32	12	37
−83, −82	50	32	15	50
−81, −80	47	34	22	78
−79, −78	44	46	29	85
−77, −76	35	54	53	83
−75, −74	43	61	52	73
−73, −72	39	55	75	82
−71, −70	43	48	87	63
−69, −68	44	45	83	54
−67, −66	39	45	86	45
−65, −64	31	39	80	40
−63, −62	28	26	68	34
−61, −60	27	21	69	34
−59, −58	23	21	52	33
−57, −56	24	22	54	22
−55, −54	9	16	32	18
−53, −52	7	8	29	16
−51, −50	11	6	25	10
−49, −48	7	6	15	9
−47, −46	3	4	14	4
−45, −44	4	2	15	4
−43, −42		3	6	5
−41, −40		1	7	2
−39, −38		2	3	
−37, −36			2	
−35, −34			3	
−33, −32			1	
		degrees Fahrenheit		
Mean	−77·2	−71·0	−65·2	−73·3
Standard error of mean	1·5	1·3	1·0	1·1
Total number of observations	Dec. 342 Jan. 239 Feb. 213	Mar. 231 Apr. 207 May 233	June 326 July 331 Aug. 338	Sept. 321 Oct. 354 Nov. 331
	794	671	995	1,006

The table gives seasonal frequencies of tropopause temperatures irrespective of the height of the tropopause. Frequencies for the three types of tropopause and for the four daily ascents (normally at 0000, 0600, 1200, 1800 G.M.T.) have been combined. Means and standard errors of means are also given. The standard error of the mean has been taken as $\sqrt{(\text{variance} \div n/3)}$ where n is the number of days in the period. Investigations by Brooks and Carruthers into the effect of persistence in meteorological data have shown that, in general, observations of temperature on n consecutive days are roughly equivalent to $n/3$ independent observations. The factor 3 is used by Carruthers* in a discussion of the accuracy of mean values of temperature. Frequencies in this table are based on four observations a day so 12 observations have been taken as equivalent to only one independent observation. This is possibly an over-estimate of the dependence and so the true mean probably departs from the sample mean by a slightly smaller value than that given for the standard error. It has been considered of more value to give standard errors of the mean than standard deviations as the distributions are clearly not normal.

D. DEWAR

Geophysical prospecting below the bed of the deep sea

The Department of Geodesy and Geophysics of Cambridge University carried out experiments from the Ocean Weather Ship *Weather Explorer* at Station JIG, during August 1949. These experiments employed a new technique of seismic prospecting developed for use in the deep sea.

The shock waves necessary in such prospecting were obtained from standard Naval depth charges set to fire at 150 fathoms. These waves travelled by different routes to hydrophones positioned 20 fathoms below Sono-Radio Buoys which transmitted the information back to the ship.

By analysing the sound travelling through the ground for distances between charge and buoy varying between 6 and 20 miles, it is possible to determine the thicknesses of the various layers constituting the sea bed. The preliminary analysis shows that the soft sediments are about 7,000 ft. thick, and that below the sediments is a layer about 9,000 ft. thick which consists of a hard rock similar to that lying a few thousand feet below the continents. The rock below this again extends to a depth which cannot be determined from the results, but of which the composition is similar to that supposed to exist at a depth of some 40,000 ft. below the continental surface.

REVIEW

British thunderstorms 1949, May 14–16. Prepared by the Thunderstorm Census Organization. Research Publication 49/15. Chart $37\frac{1}{4}$ in. × $39\frac{3}{4}$ in. Huddersfield, 1949.

Series of charts are prepared by the Thunderstorm Census Organization showing the main overhead storm areas and principal damage areas. Additionally strokes to earth outside damage areas are separately depicted and isochrones of the storm centres are shown hourly.

*CARRUTHERS, N; The accuracy of a mean of n temperature observations as an estimate of the mean temperature for a particular month. *Met. Mag., London*, **78**, 1949, p. 65.

These charts meet several of the primary needs of Electrical Research Authorities* in that they show the approximate time when the storm is overhead at a given point and the isochrones show the general direction of movement. Further, the severity of the storm is brought out quite well by the charting of the principal damage areas, and by the records of strokes to earth, although of course these latter are unlikely to be fully representative over sparsely populated areas.

The charts themselves are on a scale of 10 miles to the inch and show the administrative county divisions in outline; the elements set out above are plotted in black. The chart for May 14–16, 1949, has been sent for review and an immediate criticism is that this period has more than one series of storms on different days over the same areas; this has made the chart difficult to read, it would therefore seem that these charts are best restricted to one 24-hour period for each chart, unless storm areas do not overlap. Other charts restricted to a single day have been seen and an extremely clear picture of the thunderstorm activity of the day is depicted and the damage areas stand out most clearly; the chart also has inset a selection of relevant upper air ascents extracted from the *Daily Weather Report.*

BOOKS RECEIVED

L'action individuelle des taches solaire sur les phénomenes terrestres, by H. Mémery. Size: 9 in. × 6¼ in., pp. 40. Observatoire de Physique solaire et de Météorologie. Talence (Gironde), 1948.

Precipitation affected by solar radiation, by C. G. Abbot. *Smithson. misc. Coll.* **107**, No. 9. Size: 9½ in. × 6¼ in., pp. 4. Smithsonian Institution, Washington, D.C. 1947.

THE WEATHER OF NOVEMBER 1949

Mean pressure was about 996 mb. south-westward of Iceland. It was between 1020 and 1025 mb. in and around the Azores and in the U.S.A. over an area including most of Oregon, Idaho, Utah and Nevada.

November 1949 was the first month since August 1948, with the exception of May 1949, in which mean pressure was below normal over most of Europe. The deficiency extended from the central Mediterranean north-westwards across central Europe and the British Isles to Iceland and from there westwards and south-westwards to most of North America and amounted generally to between 5 and 8 mb. Mean pressure was above normal north-eastward of Iceland, in northern Norway and in Sweden (by 10 mb. at Harparanda) and also over a considerable area centred near the Azores.

In the British Isles the weather of November was unsettled, wet on the whole (although there was a large area in central and north Scotland with less than the average rainfall) and rather mild.

During the opening days a wedge of high pressure over the southern districts of the British Isles moved slowly south, while troughs of low pressure associated with a depression near Iceland moved across the northern districts. Rather cold, fair weather, apart from mist and fog, prevailed in the south-east, while rain occurred at times in the west and north. Subsequently very unsettled con-

*See 1. GOLDE, R. M.; Thunderstorm observations. *Met. Mag., London*, **77**, 1948, p. 49.
2. BOWER, S. M.; Thunderstorm observations. *Met. Mag., London*, **77**, 1948, p. 207.
3. GOLDE, R. M.; Thunderstorm observations. *Met. Mag., London*, **77**, 1948, p. 208.

ditions set in and persisted until the 13th. On the 4th a small depression developed in mid Atlantic and moved rapidly north-east deepening as it moved. In the British Isles, rain, heavy in places, occurred on the 4th and 5th, while winds were strong, reaching gale force. Rainfall on the 4th amounted to 2·99 in. at Glenquoich, Inverness-shire and 2·47 in. at Blaenau Festiniog, Merioneth, on the 4th. On the 6th another depression developed in mid Atlantic and moved quickly south-east to France; this also deepened as it moved and there were showers with local hail and thunder in the British Isles. Again on the 8th and 9th a deep Atlantic depression moved north-east to the south-west of Iceland and then turned east; rain occurred fairly generally and winds were strong, while gales were experienced at exposed places in the west. On the 11th a disturbance off north-west Ireland moved east-north-east, while associated troughs moved east; widespread gales occurred on the 12th when a strong WNW. gale affected the Bristol Channel; a ship was wrecked off Lundy on the 13th and many of the crew were drowned. Rainfall was heavy locally in the north-west and thunder occurred in some places (for example, 3·44 in. at Troutbeck and 3·26 in. at Watendlath Farm, in Cumberland). An improvement (apart from fog) took place in eastern districts on the 14th and 15th with the eastward passage of a wedge of high pressure, but a trough over western districts caused further rain there. Subsequently the trough moved very slowly east giving more rain in the western half of the country on the 16th and general and rather heavy rain on the 17th, with gales in the west and north. Thereafter another less vigorous trough moved slowly east over the country; rain or showers occurred, the rainfall being moderately heavy on the 20th. By the 21st a new deep depression was situated west of Scotland, where it remained almost stationary until the 23rd, while troughs moved over the British Isles. Showery weather prevailed, with bright periods locally and gales at exposed stations. On the 23rd the main depression moved a little east and filled while a small secondary off south-west Ireland moved to France and became less deep. Subsequently a complex area of low pressure was established over France and the south Baltic. Rain occurred at times in most parts of the British Isles, being heavier on the east coast of Britain; it was mainly dull, with NE. to N. winds. Thereafter a ridge of high pressure associated with an anticyclone on the Atlantic moved south over this country on the 28th and 29th. Meanwhile depressions in the far north moved north-east or east. Occasional rain occurred in the north but only slight, scattered rain in south. Some sunny periods were recorded at most stations on the 28th, in the south on the 29th and in the south-west also on the 30th.

The general character of the weather is shown by the following provisional figures:—

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales ..	62	21	+0·9	125	+2	99	23
Scotland	58	13	+1·7	111	+2	88	19
Northern Ireland ..	57	26	+1·0	101	0	104	26

RAINFALL OF NOVEMBER 1949

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ..	2·15	91	*Glam.*	Cardiff, Penylan ..	4·77	118
Kent	Folkestone, Cherry Gdns.	4·57	141	*Pemb.*	St. Ann's Head.. ..	5·19	130
,,	Edenbridge, Falconhurst	3·66	103	*Card.*	Aberystwyth	6·90	187
Sussex	Compton, Compton Ho.	4·79	126	*Radnor*	Tyrmynydd	8·64	130
,,	Worthing, Beach Ho. Pk.	3·47	108	*Mont.*	Lake Vyrnwy	8·26	142
Hants.	Ventnor, Roy. Nat. Hos.	3·93	122	*Mer.*	Blaenau Festiniog ..	11·02	103
,,	Bournemouth	3·82	112	*Carn.*	Llandudno	3·10	107
,,	Sherborne St. John ..	3·09	108	*Angl.*	Llanerchymedd ..	4·49	107
Herts.	Royston, Therfield Rec.	2·54	109	*I. Man.*	Douglas, Borough Cem.	4·77	101
Bucks.	Slough, Upton	2·27	102	*Wigtown*	Port William, Monreith	4·09	95
Oxford	Oxford, Radcliffe ..	2·52	110	*Dumf.*	Dumfries, Crichton R.I.	5·16	140
N'hant	Wellingboro', Swanspool	2·19	102	,,	Eskdalemuir Obsy. ..	6·62	114
Essex	Shoeburyness	2·02	95	*Roxb.*	Kelso, Floors	2·88	125
Suffolk	Campsea Ashe, High Ho.	2·16	97	*Peebles.*	Stobo Castle	4·16	126
,,	Lowestoft Sec. School ..	2·23	95	*Berwick*	Marchmont House ..	3·24	108
,,	Bury St. Ed., Westley H.	2·15	93	*E. Loth.*	North Berwick Res. ..	3·09	138
Norfolk	Sandringham Ho. Gdns.	2·71	109	*Midl'n.*	Edinburgh, Blackf'd. H.	3·51	157
Wilts.	Bishops Cannings ..	2·91	102	*Lanark*	Hamilton W. W., T'nhill	3·73	104
Dorset	Creech Grange ..	4·07	99	*Ayr*	Colmonell, Knockdolian	4·66	93
,,	Beaminster, East St. ..	4·77	120	,,	Glen Afton, Ayr San. ..	7·78	141
Devon	Teignmouth, Den Gdns.	4·56	143	*Bute*	Rothesay, Ardencraig ..	6·94	137
,,	Cullompton	5·13	149	*Argyll*	L. Sunart, Glenborrodale	9·85	132
,,	Barnstaple, N. Dev. Ath.	3·60	92	,,	Poltalloch	8·93	159
,,	Okehampton, Uplands	6·62	124	,,	Inveraray Castle ..	10·52	125
Cornwall	Bude School House ..	4·95	139	,,	Islay, Eallabus		
,,	Penzance, Morrab Gdns.	4·98	109	,,	Tiree	7·40	153
,,	St. Austell	6·81	138	*Kinross*	Loch Leven Sluice ..	3·80	106
,,	Scilly, Tresco Abbey ..	5·10	148	*Fife*	Leuchars Airfield ..	2·37	103
Glos.	Cirencester	2·94	99	*Perth*	Loch Dhu	8·57	99
Salop	Church Stretton ..	3·67	118	,,	Crieff, Strathearn Hyd.	3·57	82
,,	Cheswardine Hall ..	2·73	105	,,	Pitlochry, Fincastle ..	3·67	99
Staffs.	Malvern, Free Library	3·04	121	*Angus*	Montrose, Sunnyside ..	3·57	135
Worcs.	Birmingham, Edgbaston	3·26	137	*Aberd.*	Braemar	3·95	103
Warwick	Thornton Reservoir ..	3·34	148	,,	Dyce, Craibstone ..	5·06	155
Leics.	Boston, Skirbeck ..	2·43	122	,,	Fyvie Castle	3·63	105
Lincs.	Skegness, Marine Gdns.	2·10	97	*Moray*	Gordon Castle	2·45	85
,,	Mansfield, Carr Bank ..	3·07	126	*Nairn*	Nairn, Achareidh ..	2·59	115
Notts.	Buxton Terrace Slopes	6·78	145	*Inv's*	Loch Ness, Foyers ..	2·90	74
Ches.	Bidston Observatory ..	3·80	152	,,	Glenquoich	11·81	97
Lancs.	Manchester, Whit. Park	4·65	176	,,	Fort William, Teviot ..	8·47	103
,,	Stonyhurst College ..	4·92	109	,,	Skye, Duntuilm ..	6·32	105
,,	Blackpool	3·62	104	*R. & C.*	Tain, Tarlogie House ..	1·58	53
Yorks.	Wakefield, Clarence Pk.	3·69	174	,,	Ullapool	4·15	80
,,	Hull, Pearson Park ..	3·87	177	,,	Applecross Gardens ..	6·29	97
,,	Felixkirk, Mt. St. John	3·40	149	,,	Achnashellach	8·07	93
,,	York Museum ..	3·25	156	,,	Stornoway Airfield ..	5·77	104
,,	Scarborough	3·39	137	*Suth.*	Loch More, Achfary ..	6·68	78
,,	Middlesbrough.. ..	2·82	133	*Caith.*	Wick Airfield	2·84	90
,,	Baldersdale, Hury Res.	4·80	130	*Shet.*	Lerwick Observatory ..	6·67	157
Nor'ld	Newcastle, Leazes Pk.	3·12	133	*Ferm.*	Crom Castle	3·92	113
,,	Bellingham, High Green	4·35	127	*Armagh*	Armagh Observatory ..	2·42	85
,,	Lilburn, Tower Gdns. ..	3·10	93	*Down*	Seaforde	2·75	73
Cumb.	Geltsdale	4·75	145	*Antrim*	Aldergrove Airfield ..	2·41	74
,,	Keswick, High Hill ..	10·10	178	,,	Ballymena, Harryville	4·33	107
,,	Ravenglass, The Grove	4·83	108	*Lon.*	Garvagh, Moneydig ..	4·70	120
Mon.	Abergavenny, Larchfield	5·23	137	,,	Londonderry, Creggan	5·38	131
Glam.	Ystalyfera, Wern House	7·89	120	*Tyrone*	Omagh, Edenfel ..	5·06	133

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, JULY 1949

Stations	Pressure		Temperatures							Relative humidity	Mean cloud amount	Precipitation			Bright Sunshine	
			Absolute		Mean values											
	Mean of day M.S.L.	Diff. from normal	Max.	Min.	Max.	Min.	½ Max. and Min.	Diff. from normal	Wet bulb			Total	Diff. from normal	Days	Daily mean	Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	oktas	in.	in.		hr.	%
London, Kew Observatory	1019·8	+3·9	85	50	75·6	57·4	66·5	+3·5	58·9	63	4·8	1·12	−1·05	7	8·1	50
Gibraltar	1016·4	−0·4	91	63	84·0	69·1	76·5	+1·7	69·9	70	2·3	0·00	—	0	11·3	79
Malta	1015·8	+1·1	93	65	85·5	70·0	77·7	−0·6	71·9	62	1·4	0·01	—	1	12·4	87
St. Helena	1019·1	−1·0	70	54	64·5	55·0	59·7	+1·4	55·2	94	6·8	2·34	−1·79	13	—	—
Lungi, Sierra Leone	1013·7	—	87	69	83·1	72·7	77·9	—	74·2	92	6·7	35·68	—	29	3·5	27
Lagos, Nigeria ..	1013·8	+0·7	88	67	82·6	70·6	76·6	−1·4	74·9	89	7·5	7·67	—	21	2·5	20
Kaduna, Nigeria ..	1011·8	—	87	64	82·5	67·3	74·9	+0·7	70·0	82	7·2	5·73	−4·89	12	6·3	50
Chileka, Nyasaland	1022·5	−0·7	82	51	75·4	56·1	65·7	+0·6	57·3	69	3·5	0·02	−0·11	1	7·1	63
Lusaka, Rhodesia ..	1020·2	−0·3	83	44	77·0	50·5	63·7	+2·2	53·3	67	0·8	0·00	−0·01	0	9·8	87
Salisbury, Rhodesia	1023·0	−0·6	76	37	70·5	44·9	57·7	+1·0	48·5	63	1·7	0·12	+0·09	1	8·1	72
Cape Town	1021·1	−0·2	80	39	65·2	44·8	55·0	+0·3	45·5	74	4·0	3·88	+0·26	18	—	—
Palmietfontein, S. Africa	1026·7	—	71	20	64·5	31·3	47·9	—	35·5	67	1·0	0·01	—	1	9·8	—
Mauritius	1020·4	−0·1	79	53	75·4	62·2	68·8	+0·5	62·8	71	3·7	1·24	−1·04	20	8·5	77
Calcutta, Alipore Obys.	1000·0	+1·1	94	76	89·9	79·5	84·7	+1·0	80·4	85	6·5	14·31	+1·61	23	4·0	30
Bombay	1003·3	−0·6	90	74	86·6	78·0	82·3	+0·9	78·4	86	6·4	23·64	−0·63	30	2·6	20
Madras	1004·6	+0·1	96	73	93·0	77·5	85·3	−2·3	76·1	75	6·7	2·99	−0·85	15	5·8	45
Colombo, Ceylon ..	1009·0	−0·1	86	71	85·2	75·8	80·5	−0·7	77·1	87	6·6	6·53	+2·10	25	5·6	45
Singapore	1009·4	+0·5	90	73	87·1	76·3	81·7	+0·4	76·6	80	5·3	7·40	+0·61	14	6·6	54
Hongkong	1006·6	+1·9	92	74	88·5	78·9	83·7	+1·2	78·2	81	—	6·71	−7·71	16	7·9	59
Sydney, N.S.W. ..	1018·8	+0·5	75	41	63·3	46·0	54·7	+2·0	47·2	75	3·8	2·30	−2·50	8	6·5	64
Melbourne	1017·3	−1·6	62	35	56·4	43·2	49·8	+1·1	45·3	79	5·5	2·22	+0·36	14	3·7	38
Adelaide	1019·1	−1·1	72	39	59·4	45·4	52·4	+0·5	47·4	73	5·0	2·25	−0·39	16	3·7	37
Perth, W. Australia	1017·2	−1·8	74	45	65·7	51·8	58·7	+3·5	53·5	78	5·5	6·56	0·00	23	4·0	39
Coolgardie	1018·8	−1·1	81	35	64·8	44·7	54·7	+3·5	48·9	70	4·0	1·95	+1·08	10	—	—
Brisbane	1019·9	+1·5	74	39	68·3	47·4	57·9	−0·6	51·8	63	2·7	0·82	−1·38	8	7·8	74
Hobart, Tasmania	1012·7	−1·0	62	34	54·8	41·1	47·9	+2·2	42·1	73	5·8	3·25	+1·07	14	4·4	47
Wellington, N.Z. ..	1012·8	−1·9	60	36	54·2	44·5	49·3	+2·9	47·3	85	5·9	5·61	−0·02	16	3·5	37
Suva, Fiji	1014·8	+0·8	86	64	78·2	69·5	73·9	+0·5	70·0	80	6·0	6·54	+1·61	25	4·3	39
Apia, Samoa ..	1012·0	+0·3	89	66	84·8	71·9	78·3	+0·1	74·1	80	4·2	7·05	+3·58	18	8·5	75
Kingston, Jamaica	1014·5	−0·2	93	71	90·1	74·5	82·3	+0·6	72·9	79	4·0	2·87	+1·25	8	7·4	57
Grenada, W. Indies	—	—	90	71	85·0	74·0	79·5	+0·3	75·0	78	4·0	6·51	−2·92	26	—	—
Toronto	1015·9	−1·5	93	53	83·0	64·9	73·9	+4·8	63·5	73	4·7	3·14	+0·30	8	8·9	59
Winnipeg	1012·5	+0·2	95	44	79·3	56·3	67·8	+1·4	57·1	82	5·4	2·29	−0·81	12	8·9	56
St. John, N.B. ..	1014·1	+0·5	83	49	72·9	56·0	64·5	+4·1	54·9	61	6·8	1·09	−2·54	9	7·7	50
Victoria, B.C. ..	1017·4	+0·1	80	44	69·6	51·0	60·3	+0·2	51·0	87	4·9	1·12	+0·70	8	10·5	67